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RATE OF COMBUSTION OF THREE-COMPONENT MIXTURE SYSTEMS

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

RATE OF COMBUSTION OF THREE-COMPONENT MIXTURE SYSTEMS

V. S. Nikiforov, N. N. Bakhman,
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The effect of additions of the powders of aluminum, magnesium, boron and others upon the rate of combustion of model mixtures based on ammonium perchlorate (APC) [ПХА] and potassium perchlorate (PPC) [ПХК] was studied in works [1-3]. It was shown that the effect of additions of metals is determined primarily by the size of metal particles. The finely-dispersed powders of metals can, depending upon the nature of the metal, substantially increase the rate of combustion, but coarsely-dispersed powders only reduce it.

In this article, using model mixtures of APC + polystyrene (PS) [ПС] and PPC + PS, the effect of the percentage of the addition of finely-dispersed and relatively coarsely-dispersed aluminum is studied in detail. Also studied is the effect of the relationship between the oxidizer and PS on the effectiveness of action of the aluminum addition.

Powder-like components with effective particle size[1] $\bar{d}$, equal to APC and PPC to $\sim$10 μm, and for PS $\sim$5 μm, were used.

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[1]Particle size was computed according to the specific surface size measured on the PSKh-4 instrument.

Finely-dispersed PAK-4 brand aluminum (with a scale-like particle form; $\bar{d} \simeq 3$ μm) and relatively coarsely-dispersed aluminum with a spherical particle form; $\bar{d} \simeq 20$ μm were used.

The relationship between the oxidizer and the polystyrene will be designated by quantity $\alpha_0 = \frac{m_{ок}/m_г}{(m_{ок}/m_г)_{стех}}$. The aluminum was introduced at constant α_0, i.e., a ternary mixture was calculated according to the principle (100-x)% mixture (oxidizer + + PS, α_0) + x% of aluminum.

The prepared mixtures were pressed into cylindrical brass containers. The obtained charges were consumed in a cylinder of constant pressure at p = 40 atm. We measured the average rate of combustion $\bar{u} = h/\tau$, where h - height of the charge, and τ - combustion time measured with the aid of a quartz crystal pressure sensor, $Z = u_{Al}/u_0$ - effectiveness of aluminum action, where u_{Al} and u_0 - rates of combustion for the compounds with aluminum and without it.

Effect of the percentage of addition of aluminum. It is interesting first of all to note (Fig. 1) that with an increase in the percentage of aluminum from 0 to 5-8%, the combustion

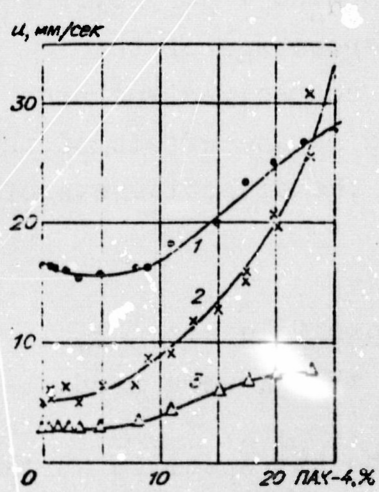


Fig. 1. Dependence of the rate of combustion of an APC + PS + PAK-4 mixture upon the percentage of aluminum in it at a different ratio of components in the starting binary mixture APC + PS; p = 40 atm. 1 - α_0 = 0.5; 2 - α_0 = 2.1; 3 - α_0 = 0.15. Designation: сек = s.

rate of APC + PS mixtures virtually remains constant, and for a mixture with α_0 = 0.5 even a certain reduction in the rate of combustion is observed. According to the degree of further increase in the percentage of aluminum, the combustion rate begins to rapidly increase. The most rapid increase was observed with an excess of oxidizer in the starting compound (α_0 = 2.1). With an aluminum content above 23%, u of the compound with α_0 = 2.1 becomes higher than the rate of combustion for the compound with α_0 = 0.5. For a mixture with a high percentage of PS (α_0 = 0.15), increase in the rate of combustion according to the measure of adding metal is retarded with a high percentage of aluminum content.

The maximum rate of combustion (in terms of percentage of aluminum) in the experiments with mixtures APC + PS + PAK-4 was not achieved; it can only be asserted that it lies at an aluminum content of $\geq$25%.

Besides the rate of combustion, let us examine the dependence of the effectiveness of aluminum action upon the percentage of its addition. From Fig. 2 it follows that the effectiveness of the aluminum is maximum for compound α_0 = 2.1. However, Al is effective also in the compound with a high excess of PS (α_0 = = 0.15), which is connected with the low rate of combustion of the starting (without aluminum) compound with α_0 = 0.15, which is equal to 2.9 mm/s.

Let us examine the results of the experiments on the effect of additions of coarsely-dispersed aluminum on the rate of combustion for APC + PS mixtures. The nature of curves u(Al%) (Fig. 3) is entirely different that in the case of finely-dispersed aluminum. Thus, for compound α_0 = 0.5, the rate of combustion is reduced according to the increase in aluminum, for compound α_0 = 1 it virtually remains constant and only for a compound with α_0 = 2.1 does it increase, but it is substantially less abrupt

as compared with the analogous curve for finely-dispersed aluminum (see Fig. 1).

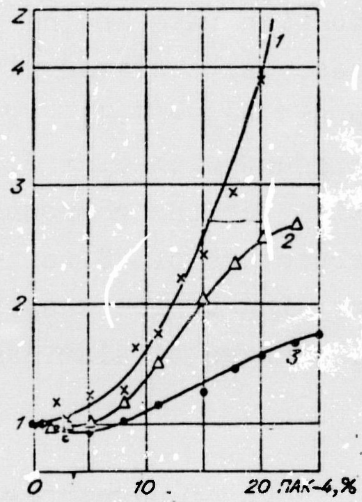


Fig. 2.

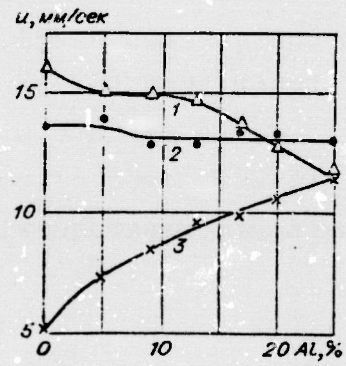


Fig. 3.

Fig. 2. Dependence of the effectiveness Z of the action of aluminum on APC + PS compounds upon the percentage of aluminum in mixture with a different ratio of components; p = 40 atm. 1 - α = 2.1; 2 - α_0 = 0.15; 3 - α_0 = 0.5.

Fig. 3. Dependence of the rate of combustion of mixture APC + + PS + Al (20 μm) upon the percentage of aluminum in a mixture with a different ratio of components in the starting binary mixture APC + PS; p - 40 atm. 1 - α_0 = 0.5; 2 - α_0 = 1.0; 3 - α_0 = 2.1.

Let us also examine the effect of additions of finely-dispersed and coarsely-dispersed aluminum on the combustion of APC + PS mixtures. Data on the rate of combustion of PPS + PS + Al mixtures are shown in Fig. 4.

With the introduction of finely-dispersed aluminum, the rate of combustion increases substantially, especially sharply for a compound with α_0 = 2. The rate of combustion for a compound with α_0 = 2 becomes higher than for a compound with α_0 = 0.5 already at an aluminum content of ~10%. Upon the introduction of coarsely-dispersed aluminum, the rate of combustion for compounds based on PPC is decreased both when α_0 = 0.5, and when α_0 = 2.

It is necessary, however, to note that for binary mixture APC + + PS with $\alpha_0 = 2.1$ ($u_0 = 5.2$ mm/s) it is considerably greater than for binary mixture APC + PS with $\alpha_0 = 2$, ($u_0 = 11.0$ mm/s).

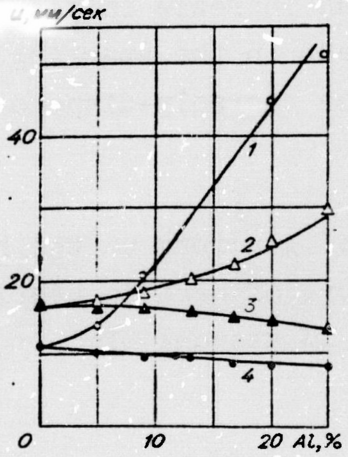
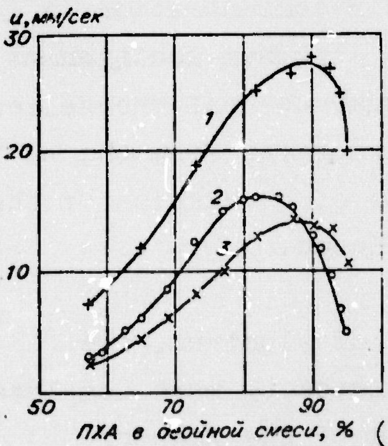


Fig. 4. Dependence of the rate of combustion of compound PPC + PS + Al upon the percentage of aluminum in the mixture at a different ratio of components in the starting binary mixture PPC + PS and different degree of dispersion of aluminum; p = 40 atm. 1 - $\alpha_0 = 2$; $d_{Al} \sim 3$ μm; 2 - $\alpha_0 = 0.5$; $d_{Al} \sim 3$ μm; 3 - $\alpha_0 = 0.5$; $d_{Al} \sim 20$ μm; 4 - $\alpha_0 = 2$; $d_{Al} \sim 20$ μm.

Effect of the relationship between the oxidizer and organic fuel. The previous section was a detailed examination of the dependence of the rate of combustion of quantity Z upon the percentage of additions of aluminum for three values of α_0. The dependence of rate of combustion and quantity Z upon α_0 was studied in detail for a mixture of 80% (APC + PS) + 20% Al (Fig. 5).



(1)

Fig. 5. Dependence of the rate of combustion of compound 80% (APC + PS) + 20% Al upon APC content in the binary mixture; p = 40 atm. 1 - mixture with 20% PAK-4; 2 - mixture without aluminum; 3 - mixture with 20% Al (20 μm).
KEY: (1) APC in the binary mixture, %.

For binary mixtures APC + PS and PPC + PS, the maximum of the rate of combustion lies at substantial excess in polystyrene

(α_0 = 0.5) [4]. With the introduction of 20% finely-dispersed aluminum, curve u(APC, %) rises upward and moves to the side of high oxidizer content. If 20% of coarsely-dispersed aluminum is introduced, then the maximum on curve u(APC, %) also moves to the side of high oxidizer content; however, an increase in rate of combustion is observed only with an APC content in the starting mixture of $\geq$90%, and with an excess of PS the coarsely-dispersed aluminum only reduces the rate of combustion.

Discussion of the results. The effect of aluminum on the rate of combustion is connected with the expenditure of heat in heating the aluminum particles and with heat release on account of particle combustion in the area of influence.

The first factor leads to a reduction in the rate of combustion, the second - to its increase. The competition of heat transfer and heat arrival determines how the rate of combustion for the mixture upon introduction of aluminum additions will vary [1, 2].

Let us examine, from this point of view, the basic results of this work. It is known that the ignition of the suspended matter of the metal particles is relieved when their concentration is increased. Therefore, if the percentage of aluminum addition is small, then the particles only absorb the heat to heat themselves up, and their ignition and burning occur rather far from the charge's surface. Correspondingly, the rate of combustion of the mixtures does not increase and is even reduced.

With an increase in percentage content of aluminum, the particle ignition time is decreased, which leads to more complete combustion of the aluminum within the limits of the zone of influence and to an increase in the rate of combustion.

With the change of the mixture's composition, there is a change in the medium in which the particles are ignited and burn. It is natural that an increase in the content of oxidizer in the starting mixture (i.e., an increase in α_0) is a favorable factor.

Coarsely-dispersed particles are difficult to ignite and burn slowly. Therefore, with the addition of coarsely-dispersed aluminum, the rate of combustion is reduced. Only compounds with a high excess of oxidizer, where an increase in the rate of combustion even with additions of coarsely-dispersed aluminum is observed, are the exception.

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